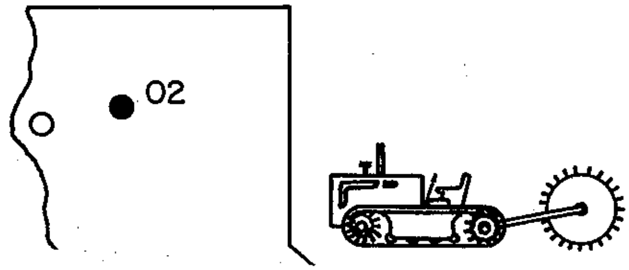
EVALUATION OF THE NUCLEAR COMPACTION TEST METHOD

DISTRICT 02



67-06

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 632697-3

Prepared in Cooperation with the U.S. Department of Commerce, Bureau of Public Roads MARCH 1967

State of California
Department of Public Works
Division of Highways
Materials and Research Department

March 1967

Lab. Auth. 632697-3

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

INTERIM REPORT #3

on

"EVALUATION OF THE NUCLEAR COMPACTION TEST METHOD"

DISTRICT 02

Study made by .... Foundation Section
Under general direction of .... Travis Smith
Work supervised by .... W. G. Weber, Jr.
Report prepared by .... C. T. Gipson
John V. Kelly

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

Attach.
cc:LR Gillis

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Supplemental Statement

Reference is made to the letter from Mr. D. J. Steele, Division Engineer for the Bureau of Public Roads, dated December 7, 1966, concerning interim report #1. In this letter Mr. Steele stated that for the Bureau's purposes "it would not be necessary to present formal interim reports" on each project in the other nine districts.

The original purpose in preparing these interim reports was (1) provide engineers, in this department and in the districts, with information and data in an "approved and organized" form for their use before the final report is published, and (2) "spread" the routine compilation and analysis of a huge quantity of data over a broad base of time so that effort can be concentrated on the basic aims of the study at the final report stage.

For these reasons it is felt that the continued preparation of these interim reports, as the individual projects are completed, is very desirable. In the future it is proposed to provide only a brief discussion pertinent to the individual project and include tables and plots of the data accumulated.

This report on the District 02 project is patterned after the previous interim reports #1 on District 03 and #2 on District 05. These reports depicted projects on which backscatter type instruments were utilized. Since the final draft was near completion and this project utilized a transmission type gage, at the time Mr. Steele's correspondence was received, it was decided to proceed under the original format.

ACKNOWLEDGEMENTS

The construction contract upon which this study was conducted was under the general supervision of the District 02 Construction Engineer and the direct supervision of the Resident Engineer. The successful application of the nuclear gage, and compliance to Test Method 231-B, is due to the efforts of the Resident Engineer, and the two test operators.

This study was financed with Bureau of Public Roads 1-1/2 percent research funds under authorization HPR 1(2) FO403.

INTRODUCTION

The increasing rate of embankment placement has created a need for increasing the efficiency of compaction control. This need has caused the Materials and Research Department of the California Division of Highways to initiate a statewide research program specifying that nuclear gages and a modified statistical test method be used in lieu of California Test Method 216-F on ten construction projects in nine highway districts.

This data report will record the results and problems encountered during this research in District 02 on road Sha-05-PM 35.5/40.2 (Figure 1), which is in forested, mountainous, north central California about 20 miles north of Redding.

This report will examine the application of the test method to specification control, on this contract, and analyse the data obtained from the field operation of the nuclear equipment.

It is not the purpose of this report to make recommendations or draw conclusions; as this will be done when complete data has been accumulated from all the projects.

METHOD OF OPERATION

The contract is a 4-lane freeway with frontage roads and connections constructed by grading and surfacing with portland cement concrete on cement treated base over aggregate subbase and with asphalt concrete on aggregate base over aggregate subbase. Over 3 million cubic yards of roadway excavation and more than 9000 cubic yards of structure backfill were moved and compacted on this project. As the nuclear gages and statistical concept for compaction control is a new test method it was necessary to place the following statement in Section 5-1.02 of the contract special provisions.

> "Wherever relative compaction is specified in the Standard Specifications to be determined by Test Method Nos. Calif. 216 or 312 the relative compaction will be determined by experimental nuclear Test Method No. Calif. T-231. Copies of this experimental test method may be obtained at the Materials and Research Department, Division of Highways, Sacramento, California, and will be furnished on request."

In April 1965 a one week class, covering the basic concepts of nuclear physics, health safety, application of the test method and operation of the nuclear equipment, was given in Sacramento. The resident engineer, a progress sampler, and two operating technicians from the project attended this class. Upon the completion of the instruction, these people returned to the project with a Troxler transmission type gage (Figure 2).

The model SCM-227 probe and model 200-B scaler form a complete density and moisture measuring system. A two millicurie source of Radium-Berylium is at the end of a rod which can be extended into the material to be measured from four to twelve inches. The absorption effect of radiation acting on the soil is translated into counts per minute by the scaler for density determinations. Soil moisture content is determined by neutron moderation with the source in the backscatter position.

During the early stages of the project, it was necessary to check the validity of the moisture and density calibration curves furnished with the nuclear device. These curves are a plot of nuclear readings versus wet density. In accordance with Test Method 231-B (Appendix) the nuclear determinations were checked against the in-place wet density as indicated by the sand volume test. Periodic checks were performed during the routine testing to insure the accuracy of these curves.

As construction progressed these tests revealed that the moisture curves were changing in each soil type. That is, the clayey overburden required a different moisture curve than the rocky shale encountered deeper in the cuts. This peculiarity of the moisture curves persisted later in the contract when placing AS, AB, and structure backfill. Throughout the contract only the moisture curves were changed, the density curves were not altered.

The maximum impact densities changed as the soil changed, but these soil types were distinguishable visually. A maximum dry density value was established for a soil type by averaging the results of four maximum density impact cores of that soil type. This average was checked periodically to ensure competency and used with the nuclear in-place moisture and density determinations to compute the percent relative compaction.

The relative compaction was obtained at the sites within a test area. This area is the basis for the new experimental multiple testing concept of compaction control. Six sites were randomly chosen to be representative of an area. The limits of an area are dependent on the uniformity of soil and compactive effort, highway geometrics, construction pattern and factors pertinent to the operation. Area size on embankment material varied from 50 to 600 feet in length. Test areas of 300 to 1500 feet in length were tested on structural sections. Pipe pads and structure backfill were considered one area per pipe and three sites established for the control testing.

ANALYSIS OF DATA

Calibration

Several soil types were encountered on the project. Sand volume density determinations were performed on these soils after nuclear readings were obtained. The respective densities and count ratios are tabulated in Table I. This data of count ratio versus indicated wet density is plotted in Figure 3. The straight lines shown are the calibration curves furnished by the manufacturer with the Troxler equipment. The plotted points indicated to the operators that these curves were satisfactory for density determinations. The standard deviation of the points about their respective lines was found to be less than 5 lbs. per cu. ft. for the 8, 10 and 12 inch transmission depths. It can be noticed that only two points of correction were obtained for the 4 inch depth. The operators felt that since the other curves had such close correlation these two points were sufficient to check the 4 inch depth. This depth was used on AB and CTB courses.

Figures 4 and 5 indicate the six moisture content calibration curves used on the contract. These curves are plots of nuclear count ratio versus moisture content (in lbs. of water per cu. ft. of soil) as determined by the "oven dry" method. The moisture correlation data is shown in Table 2. The difference in displacement and slope of these curves can be explained by the presence of volcanics in the contract area. These volcanics (rhyolite) have an effect on the neutron moderation for moisture determination. The calculated standard deviation for the moisture content from the respective lines is about two lbs. of water per cu. ft. of soil.

Maximum Test Density Determination

Once the calibration curves for the nuclear equipment had been established the "in place" portion of the relative compaction value was determinable. The other half, or the test maximum; was a little more complex.

Due to the abundance of rock, the relative compaction value was calculated on the "dry weight basis." At the beginning of construction, test maximum dry density values were obtained for the several soils on the project. These density values were categorized by soil types on a minus 3/4" basis. A histogram of these test maximum densities is in Figure 6. Bi-weekly specific gravities were obtained on all plus 3/4" aggregate encountered in the embankments. Knowing the minus 3/4 dry density for any soil type and the specific gravity of the plus 3/4 rock; the test technicians had to ascertain the percent of plus 3/4 rock in the area tested to calculate the test maximum dry density value for that area. This percentage was determined by random sampling at the various test sites. The value obtained by this practice was verified in the field laboratory periodically. A frequency distribution of these verifications is shown in Figure 7.

Construction Control Testing

A summary of the Relative Compaction (RC) data is shown in Table 3 for materials requiring 90% and in Table 4 for those requiring 95% Relative Compaction. These tables indicate the individual test site value and the area average from the corresponding sites. It can be seen that those areas whose average relative compaction failed to meet the minimum required value have been underlined and noted as "reject."

Frequency distribution histograms of the relative compaction data (Tables 3 and 4) can be seen in Figures 8 and 9. These bar graphs represent all of the sites in the areas tested on the contract. Figure 8 indicates that, from the passing areas in which 90% relative compaction was required, the individual test sites ranged from 80 to 114% relative compaction. The average of this distribution is 94 and the standard deviation 4% relative compaction. Figure 9 depicts those areas tested for 95% relative compaction (i.e., structure backfill, AS, AB, CTB and OG). This chart indicates the same general trend as Figure 8. The individual test sites, from these passing, areas, ranged from 88 to 110% relative compaction. This distribution has an average of 97 and a standard deviation of 3% relative compaction. From Figures 8 and 9 it can be seen that a small group of failing test sites (dashed bars) are scattered throughout the passing areas. In both cases, these tests represent only 8% of the total tests from the passing areas.

It should be noted that the tests from the failing areas (shown as dashed bars in Figures 8 and 9) were excluded from the above statistical analysis. It is felt that these failing areas do not relate to the finished product, since a failed area is reworked and retested until it is accepted. The purpose of showing the failing area tests is merely to indicate the proportion and distribution of these substandard tests encountered during construction.

Frequency histograms of the area averages have been prepared. The distribution for those areas requiring 90% relative compaction is shown in Figure 10; Figure 11 illustrated the frequency of area averages where 95% relative compaction was required. As is to be expected the passing area extends upward (RC value-wise) from the minimum relative compaction specified limit. The reader should be aware that these charts do not represent a final state of compaction; as those areas which failed were normally reworked and retested until they became passing areas. The normal or bell shaped curves, superimposed on the respective charts, indicate the most probable distribution for all possible test areas (universe distribution) for each relative compaction value. The difference between the normal curve and the histogram is due to the statistical effect of increasing the probabilities of obtaining passing samples through retesting as demonstrated by Jorgensen and Watkins (1) and the limitations of sampling and testing. It can be seen in Figure 10 and 11 that a portion of each normal curve extends below 90% and 95% relative compaction, indicating that some material may still be below the specified value.

A closer look at the substandard areas, represented by dashed bars, in Figures 10 and 11, are shown in Figures 12, 13, and 14. It should be noted that most of these areas from Figure 10 were rejected on the "more than one-third of test sites below the minimum" basis[(2)], without testing all the proposed sites in that area. That is, during the testing of an area, when more than one-third of the anticipated sites failed to meet the minimum required value of relative compaction, the testing was terminated and the area was "rejected." Therefore two presentations of the individual tests, from failed areas where 90% relative compaction was required, are made. Figure 12 illustrates those area averages and site values from those instances where all six sites were tested.

It can be seen that the failing areas had at least 50% of the individual sites below the required minimum relative compaction value. Even those areas in the "33% passing-67% failing" category which had 95 to 99% relative compaction test sites, had substandard averages due to the sites with 89 to 74% relative compaction. The fact that these areas failed by virtue of having below 90% average relative compaction is due to the perponderance of failing individual test sites. This supports the contention that areas containing more than one-third (33%) failing tests should be automatically classified as "failing areas". Those areas where this practice was carried out are illustrated in Figure 13.

It can be seen that testing was terminated when either more than one-third of the sites were below 90% relative compaction or when it was obvious that a passable area average was impossible due to the extreme substandard relative compaction values obtained.

Figure 14 illustrates the area averages and test site results from the failing areas where 95% relative compaction was required. This chart depicts a similar situation as Figure 12. That is, a perponderance of failing tests cause the area average to drop below the specified relative compaction value and in 94% of these areas the failings sites contained more than 33% failing tests.

DISCUSSION OF TEST OPERATIONS

During the contract a few difficulties arose, but were resolved with great dispatch. These problems will be discussed in the following paragraphs.

Malfunctions of the nuclear equipment would cause testing to terminate. The nuclear gage supplied for the contract was out of service 14% of the total working days for the project. The malfunctions and the amount of "downtime" each caused are shown in Table 5. During these periods when the gage was being fixed another gage was provided by the Materials and Research Department. The replacement gage was of the transmission type and required no adjustment of the calibration curve.

During the early stages of construction, site preparation for the seating of the gage was a major chore. The operators soon discovered that experience and technique were the key to consistency in site preparation.

The health-safety aspects of nuclear testing did not present any difficulties on this project. There was no apprehension indicated by the contractor or general public. The operators were equipped with a film badge and dosimeter to monitor exposure. The highest weekly dosage received by an operator during the contract was 14 milliroentgens equivalent man (mrem). This amount is well below the 50 mrem per week limit observed by the Materials and Research Department or the 100 mrem maximum specified by the California State Department of Public Health.

A gasoline operated generator and an electric rotary hammer was supplied for the purpose of drilling the transmission hole. This equipment was used only in extremely rocky test areas. The operators felt that the hooking-up and operation of the roto-hammer was more time consuming than labor saving. Therefore most test holes were obtained by driving a "gad" perpendicular to the test site surface.

The transportation of the nuclear gage about the job site was accomplished in a four wheel drive pickup with a canopy (see Figure 15). This vehicle could be closed and locked to protect the equipment from the elements and theft. Seat belts were used to secure the gage from jarring during rough rides across the fills.

REFERENCES

1. "Compaction - Myth or Fact?" by J. Frank Jorgensen and Robert O. Watkins, presented at the 44th Annual WASHO Conference, June 16, 1965.

2. Test Method No. Calif. T-231-B, December 30, 1964, Section F, para. 5, line 4.

TABLE I

Density Correlation Data

Count Ratio	Wet Density	Soil Type
12" Transmission Depth		
0.34	92	Shale and clay
0.40	94	Clay
0.32	97	Clay
0.35	103	Shale
0.25	109	Clay
0.21	115	Shale and clay
0.20	116	Red clay
0.21	124	Shale
0.16	124	Shale
0.19	127	Shale and clay
0.17	128	Shale and clay
0.17	128	Shale
0.14	140	Shale
10" Transmission Depth		
0.67	92	Shale and clay
0.68	94	Clay
0.56	97	Clay
0.59	103	Shale
0.45	109	Clay
0.40	116	Red clay
0.38	124	Shale
0.28	124	Shale
0.33	128	Shale
0.27	133	Clay
0.27	140	Shale
8" Transmission Depth		
1.01	94	Clay
0.90	97	Clay
0.98	103	Shale
0.79	109	Clay
0.67	116	Red clay
0.57	123	Shale
0.51	124	Shale
0.67	124	Shale
0.60	128	Shale
0.50	140	Shale
4" Transmission Depth		
1.51	128	CTB
1.40	135	CTB

TABLE 2

Moisture Correlation Data

Dodson's Pit

Count Ratio	Moisture
0.51	6
0.51	7
0.53	6
0.54	7
0.55	7
0.55	7
0.56	7
0.56	9
0.57	9
0.53	9

CTB at Antler Summit

Count Ratio	Moisture
0.37	6
0.40	6
0.47	8

AB at Shea's

Count Ratio	Moisture
0.41	3
0.42	5
0.43	5
0.44	5
0.44	6
0.45	6

Misc. Soil

Count Ratio	Moisture
0.47	4
0.54	8
0.56	9
0.57	10
0.58	10
0.58	12
0.61	15
0.61	18
0.62	18
0.64	16
0.73	19
0.79	23

Clay

Count Ratio	Moisture
0.71	25
0.72	26
0.73	31
0.79	28
0.82	29
0.84	30

SUMMARY OF RELATIVE COMPACTION DATA

90%

TABLE 3

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Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
6-16-65	P-1	94	90	96				93	X		
6-29	E-1	97	83	85				88		X	
6-30	E-2	88	94	92	96	99	93	93	X		
7-6	E-4	97	94	101	95	101	89	96	X		
7-7	E-5	90	93	98	98	101	100	96	X		
7-8	E-6	94	103	99	96	93	95	96	X		
7-9	E-7	95	97	93	84	96	96	93	X		
7-12	E-8	96	98	91	93	93	100	95	X		
7-13	E-9	91	90	93	95	88	90	91	X		
7-15	E-10	91	96	97	99	95	95	95	X		
7-16	E-11	104	100	96	93	102	96	98	X		
7-22	E-12	95	98	94	95			95	X		
7-27	E-15	92	96	94	102	93	98	96	X		
7-28	E-13	91	93	95	92	83	87	91	X		
7-28	E-14	94	95	96	98	102	98	97	X		
7-29	E-16	91	92	91	97			93	X		
8-2	E-17	89	87	90	94	96	91	91	X		
8-4	E-18	86	86	82	74	99	96	87		X	
8-4	E-19	88	93	90	96	98	101	95	X		
8-5	E-20	79	89	85	87	95	97	89		X	
8-6	E-21	97	91	95	104	100	95	97	X		
8-9	E-22	94	107	95	101	94	96	98	X		
8-10	E-23	83	90	85	90	88	92	88		X	
8-12	E-24	98	100	94	97	100	101	99	X		
8-13	E-25	86	98	93	93	100	90	93	X		
8-13	E-26	91	97	95	89	88	93	92	X		
8-16	E-27	91	93	100	98	93	90	95	X		
8-16	E-28	101	94	95	83	88	88	92		X	
8-17	E-29	100	94	92	90	90	88	92	X		
8-17	E-30	99	99	105	98	100		100	X		Retest of E-28
8-18	E-31	96	100	90	91	80	87	91	X		
8-19	E-32	103	101	92	98			99	X		
8-19	E-33	89	88	96	90	97	91	92	X		
8-20	E-34	79	91	91	90	85	87	89		X	
8-20	E-35	94	96	92	90	96	96	94	X		

HMR T-2135(Orig. 12/66)

02-Sha-05

SUMMARY OF RELATIVE COMPACTION DATA
90%
TABLE 3 (contd)

Cont. 026724

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
8-23-65	E-36	95	97	97	98	98	95	97	X		
8-23	E-37	101	94	93	91	99	97	96	X		
8-24	E-38	97	99	96	100	94	91	96	X		
8-25	E-39	88	91	98	94	95	95	94	X		
8-25	E-40	97	95	96	94	93	94	95	X		
8-25	E-42	96	96	96	98			97	X		
8-26	E-41	99	98	95	98	100	97	98	X		
8-27	E-43	93	95	94	91	90	100	94	X		
8-27	E-44	98	98	95	93	100	96	97	X		
8-30	E-45	95	96	94	98	98	98	97	X		
8-31	E-46	93	89	93	77	86	86	87		X	
8-31	E-47	96	90	93	93	94	96	94	X		
9-1	E-48	88	89	89	89			89		X	
9-1	E-49	97	92	92	92	94	92	93	X		
9-1	E-50	85	84	87	89			87		X	Retest of E-34
9-1	E-51	83	88	91	90	95	91	90	X		
9-2	E-52	94	93	99	94	96	91	95	X		
9-2	E-53	90	91	98	96	97	96	95	X		
9-3	E-54	97	102	94	91	91	93	95	X		
9-3	E-55	98	97	96	98	101	100	99	X		
9-7	E-56	92	95	94	96	92	99	95	X		
9-7	E-57	97	94	90	95	91	98	94	X		
9-8	E-58	86	87	91	88			88		X	Retest of E-23
9-8	E-59	87	85	91	98	92	91	91	X		
9-10	E-60	95	95					95	X		
9-10	E-61	98	87	94	94	96 93	97 83	93	X		
9-13	E-62	79	74	82	84	81	81	80		X	
9-13	E-63	93	95	95	92	87	95	93	X		
9-14	E-64	81	90	89	89	80	81	85		X	
9-14	E-65	97	88	96	98	90	93	94	X		
9-14	E-66	82	77	81	72			79		X	
9-15	E-67	80	89	87	87			86		X	Retest of E-66
9-15	E-68	93	91	105	100	84	94	95	X		
9-16	E-69	84	82	83	84			84		X	Retest of E-62
9-17	E-71	100	95	93	92	95	93	95	X		
9-17	E-72	93	95	87	97			93	X		Retest of E-66 & E-67

SUMMARY OF RELATIVE COMPACTION DATA

90%

TABLE 3 (contd)

02-Sha-05 Cont. 026724

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
9-21-65	E-75	96	91	92	89	92	85	91	X		
9-22	E-78	92	98	96	91			94.	X		
9-22	E-79	85	85	85				85		X	Retest of E-62 & E-69
9-23	E-80	92	90	93	93	95	91	92.	X		
9-24	E-82	81	79	85	92			82		X	
9-27	E-83	97	96	95				96	X		
9-27	E-84	93	91	88	93	92	96	92.	X		
9-28	E-85	100	96	99	99			98.	X		Retest of E-82
9-29	E-86	95	96	95				95.	X		
9-29	E-87	91	92	94				92.	X		
9-30	E-88	93	95	90	89	92	92	91.	X		
10-1	E-89	93	95	92	91			93	X		
10-4	E-90	97	94	96	98			96.	X		
10-4	E-91	95	92	95				94	X		
10-5	E-92	99	101	104				101.	X		
10-5	E-93	93	94	93	93	90	91	92.	X		
10-7	E-94	93	93	95	96	97	84	93.	X		
10-7	E-95	95	92	92				93	X		Retest of E-62, 69, & 79
10-12	E-96	101	101	102	101			101.	X		Retest of E-46
10-12	E-97	96	100	94	96			96.	X		Retest of E-50, E-34
10-13	E-98	84	87	98	102	95	99	94.	X		
10-13	E-99	88	88	96	91	95	95	92.	X		
10-15	E-100	97	97	93	95	96	99	96.	X		
10-21	E-101	100	104	87	95	82	87	92.		X	
10-22	E-102	92	93	87	87	104	104	94.	X		
10-22	E-103	98	100	100	98			99	X		
10-25	E-104	98	90	99	99	91	92	95.	X		
10-25	E-105	97	98	98	92	99	99	97.	X		
10-26	E-106	92	94	90	93			92.	X		
10-27	E-108	96	96	103	104	96	96	98.	X		
10-28	E-110	90	91	84	95	93	90	91	X		
10-29	E-111	91	94					93	X		
10-29	E-113	97	101					99	X		
11-1	E-114	93	94	92	95	95	97	94.	X		
11-2	E-116	100	92	92				94.	X		
11-2	E-117	92	92	94	92	90	97	93	X		

SUMMARY OF RELATIVE COMPACTION DATA

90%

TABLE 3 (contd)

02-Sha-05

Cont. 026724

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
11-3-65	E-119	99	99	95	94	95	89	95.	X		
11-4	E-120	94	94	93	93	82	91	91.	X		
11-5	E-121	98	94	94	94	89	89	93	X		
11-8	E-122	92	96	104	95	95	93	96	X		
11-9	E-123	99	100	100	99			100	X		
11-10	E-124	91	90	93	92	95	91	92.	X		
11-10	E-125	93	93	87	91	92	92	91.	X		
11-11	E-126	93	90	96	95			95.	X		
11-16	E-127	93	94	97	101	97	96	96.	X		
12-1	E-130	96	100	99	104	95	101	99.	X		
12-3	E-131	95	99	95	95			96.	X		
12-3	E-132	97	99	103	104			98.	X		
12-6	E-133	98	97	92	97			96.	X		
12-6	E-134	97	98	96	97			97.	X		
12-8	E-136	78	90	85	87	75	89	84.		X	
12-9	E-137	76	84	78				79.		X	
12-9	E-138-A	87	84	84				85		X	
12-9	E-139	83	89	89				87		X	
12-9	E-140	81	82	88	90	79	79	83.		X	
12-9	E-141	81	87	87	89	79	87	85.		X	
12-9	E-142	97	95	96	101	95	95	96.	X		
12-10	E-143	89	90	92	93	89	96	92.	X		
12-11	E-144	89	93	90				90.	X		
12-14	E-146	94	93	91	91			92.	X		
12-14	E-147	99	99	92	98			97	X		
12-15	E-148	101	93	94	92			95	X		
12-15	E-149	91	91	91	93			91.	X		
12-16	E-150	94	91	94				93	X		
12-17	E-152	93	100	97	98	96	92	96.	X		
12-17	E-153	91	91	91				91	X		
12-20	E-154	95	91	92	92	88	97	93	X		
12-21	E-155	89	98	93	91	95	94	94	X		
12-22	E-156	84	90	94	95	92	97	93	X		
12-23	E-157	93	101	99				98	X		
12-23	E-158	97	96	98				97	X		

02-Sha-05

SUMMARY OF RELATIVE COMPACTION DATA

90%

TABLE 3 (contd)

Cont. 026724

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
1-15-66	E-162	95	90	92	93			92	X		
1-17	E-164	91	98	91	94	101	95	95	X		
1-18	E-165	95	96	94	100			96	X		
1-19	E-167	93	92	93				93	X		
1-19	E-168	100	93	94	98			96	X		
1-20	E-169	99	103	98	93	90	96	97	X		
1-21	E-170	94	94	93	91			93	X		
1-24	E-171	93	93	93	93	88	88	91	X		
1-24	E-172	88	94	94	99			94	X		
1-25	E-173	91	91	88	91	92	90	91	X		
1-25	E-174	87	86	87	84			86		X	
1-26	E-175	91	86	93	89	92	90	90	X		
1-26	E-175A	85	85	87	88			86		X	
1-26	E-176	97	101	99	95			98	X		
1-27	E-177	91	92	92	95			92	X		
1-28	E-178	86	98	97	96	94	94	94	X		
1-28	E-179	91	91	92	9'	94	94	92	X		
1-31	E-180	90	96	96	96	95	94	95	X		
2-1	E-181	100	96	96	101	97	93	97	X		
2-2	E-182	99	102	99	87	96	98	97	X		
2-7	E-184	96	102	95	98	103	98	99	X		
2-8	E-185	89	87	92	97	92	95	92	X		
2-10	E-186	98	105	98	94	98	96	98	X		
2-11	E-187	112	112	112				112	X		Retest of E-139
2-11	E-188	108	108	114				110	X		
2-11	E-189	97	103	98	95	95	98	98	X		
2-15	E-190	94	96	93	87	93	88	92	X		
2-16	E-191	95	96	100	100	98	101	98	X		
3-4	E-196	99	95	96				96.	X		
4-13	E-202	90	91	91				90.	X		
9-13	E-212	97	95	99	103			97	X		
9-21	E-213	107	109	99				105	X		

SUMMARY OF RELATIVE COMPACTION DATA

95%

TABLE 4

02-Sha-05

Cont. 026724

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
6-22-65	B-1	96	92					94		X	
6-23	B-2	96	91	91	90	88	91	91		X	
6-24	B-3	99	95	99				97	X		Retest of B-2
6-24	B-4	96	94	95				95	X		
6-30	B-5	91	94	98				94		X	
7-8	B-6	92	93	95				93		X	
7-9	B-7	96	97	97				96	X		Retest of B-6
7-12	B-8	96	97	97				96	X		
7-15	B-9	99	98	96				97	X		
7-15	B-10	93	99	96				96	X		
7-26	B-11	100	95	96				97	X		
7-30	B-12	99	93	95				96	X		
8-9	B-12	94	93	91				93		X	
8-9	B-13	93	100	96				96	X		
8-10	B-14	97	97	94				96	X		Retest of B-12
8-16	B-15	95	99	93	97	94	98	96	X		
8-16	B-16	90	91	91				91		X	
8-19	B-17	98	98	99				99	X		
8-19	B-18	96	99	98				98	X		
8-23	B-19	93	91	89				91		X	
8-25	B-20	95	89	91	93	94	90	92		X	
8-25	B-21	95	94	96				95	X		Retest of B-19
8-25	B-22	95	96	96				96	X		Retest of B-16
8-25	B-23	95	97	90	98			95	X		Retest of B-20
8-31	B-24	95	95	95				95	X		
9-3	B-25	95	94	96				95	X		
9-10	B-26	96	96	96				96	X		
9-10	B-27	87	94	92				91		X	
9-13	B-28	94	92	95				94		X	
9-14	B-29	98	92	96				95	X		Retest of B-28
9-15	B-30	94	96	95				95	X		
9-15	B-31	97	89	97	92	86	91	92		X	
9-16	B-32	94	95	97				95	X		
9-16	B-33	96	91	89	93			92		X	
9-16	E-70	95	93	93	92	92	93	93		X	
9-17	B-34	95	92	94	94			94		X	

HMR T-2135(Orig. 12/66)

SUMMARY OF RELATIVE COMPACTION DATA

95%

TABLE 4 (contd)

02-Sha-05

Cont. 026724

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
9-17-65	B-35	95	94	98				96	X		Retest of B-31 & B-33
9-21	B-36	90	91	94				92		X	
9-21	B-37	90	92	94				92		X	
9-21	E-76	93	92	90	85			91		X	
9-22	B-38	97						97	X		Retest of B-34
9-22	B-39	96	95	95				95	X		
9-22	E-77	89	102	102				98	X		Retest of E-70
9-23	E-81	108	100	100				103	X		Retest of E-76
9-28	B-40	97	95	95				96	X		Retest of B-27
10-4	B-41	97	102	95				98	X		
10-4	B-42	94	91	89				91		X	
10-5	B-43	90	95	97				94		X	
10-7	B-44	100	98	95				98			Retest of B-43
10-8	B-45	87	85	90				88		X	
10-8	B-46	92	94	92				93		X	
10-8	B-47	95	96	96				96	X		Retest of B-46
10-11	B-49	93	95	97				95	X		Retest of B-45
10-12	OG-2	99	101	92				97	X		
10-15	B-50	101	97	99				99	X		
10-15	B-51	98	98	96				97	X		Retest of B-42
10-18	B-52	96	99	97				97	X		
10-28	B-53	97	100	96				98	X		
11-2	B-54	100	94	102				99	X		
11-3	B-55	100	95	97				97	X		
11-4	AB-1	97	97	102	98	96	95	98	X		
11-5	AB-2	103	102	103	102	100	104	103	X		
11-6	AB-3	103	95	98	100	100		99	X		
12-14	B-56	95	99	99				98	X		
12-23	B-57	97	95	90				94		X	
1-14-66	B-62	97	86	90				91		X	
1-15	B-63	98	97	97				97	X		
1-15	B-64	88	88					88		X	
1-17	B-65	96	99	95				97	X		
1-17	B-66	98	99	99				99	X		
1-18	B-67	97	98	101				99	X		

SUMMARY OF RELATIVE COMPACTION DATA
95%

02-Sha-05

TABLE 4 (contd)

Cont. 026724

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
1-18-66	B-68	92	95	97				95	X		
1-18	B-69	99	101	98				99	X		
1-19	B-70	99	99	97				98	X		
1-19	B-71	94	96	97				96	X		
2-9	B-72	102	96	99				99	X		
2-11	B-73	99	97	93				96	X		
2-14	B-74	95	98	88	96			96	X		
2-18	B-75	97	96	94				95	X		
3-1	E-194	94	95	98	96			96	X		
3-3	OG-3	97	102	97				99	X		
3-22	E-197	96	99		96			97	X		
3-23	E-198	95	97	103	98		95	98	X		
3-24	E-199	101	104	101	103	100		102	X		
3-25	E-200	97	106	97	101			100	X		
3-30	B-76	97	97	96				104	X		
3-30	E-201	99	98		99	99		99	X		
4-14	E-203	97	98	95				97	X		
4-18	E-203	101	101					101	X		
4-19	OG-15	97	105					101	X		
4-19	OG-15	90	104					97	X		
4-19	E-204	105	106		101	101	103	103	X		
4-21	E-205	98	99					99	X		
4-22	AB-4	91	86	89				89		X	
4-23	AB-5	90	85	92	93			90		X	
4-26	AS-1	101	100	101	100			101	X		
4-26	AS-2	96	99		99	100	100	99	X		
4-29	AB-7	100						100	X		
5-5	AS-3	110	98	103	99			105	X		
5-6	E-206	95	95	96	101			97	X		
5-9	AS-4	98	96	97				97	X		
5-10	AS-5	98	99					98.	X		
5-10	OG-21	95	99		94	100		97.	X		
5-11	B-78	93	89					91		X	
5-11	AS-6	95	99	98	103	99		98	X		
5-12	E-207	104	105					104.	X		

SUMMARY OF RELATIVE COMPACTION DATA

95%

TABLE 4 (contd)

02-Sha-05

Cont. 026724

Date	Test No.	Relative Compaction, % #1	#2	#3	#4	#5	#6	Avg.	Accept	Reject	Remarks
5-13-66	B-79	100	95	98				97.	X		
5-14	B-80	97	97	96				96.	X		
5-16	C-1				99	95		96.	X		
5-17	C-2	91.	92.	87.3	97.	90.	91.	91.		X	
5-17	C-2	94.	91.	92.6	86.			91.		X	
5-18	C-3	89.	85.5	81.3	85.			85.		X	
5-20	C-4	95	95	95	97	95		95	X		
5-26	E-208	97	96	97				96.	X		
"	B-81	97	97	96				96.	X		
6-6	E-210	97	97	98				97.	X		
"	E-209	97	95	96	102			97.	X		
"	AS-8	98	100	98				99.	X		
6-7	E-211	98	100	101	100			99.	X		
6-21	AS-9	97	98	98	98	98		97.	X		
6-23	AS-11	95	97	98				96.	X		
"	AS-10	95	96	101	97	97		97.	X		
6-30	AS-13	95	96	95				95.	X		
6-30	AS-14	97	96	98				97.	X		
"	AS-12	95	98	98	97			97.	X		
7-2	AS-15	96	97	96	96			96.	X		
7-6	AB-8	106	103	103	102			104	X		
7-18	C-7	109	95	105				103	X		
7-19	C-8	110	96					103	X		
7-25	AS-15A	97	95	87	89			92		X	
8-8	AS-19	98	100	101	96			99	X		
8-19	C-18	89	90	81				87		X	
8-19	C-19	95	97	97	98	99	104	99	X		
8-20	C-20	98	96	99	99	100	96	98	X		
8-20	AB-9	101	102	101	100	99	99	100	X		
8-23	C-21	103	95	100	104	101	91		X		
	C-21	101	95	101				99	X		
8-25	AB-10	101	95	96				97	X		
9-1	AB-11	95	95	96	100			99	X		
9-19	AB-12	97	96	97	95	95	97	96	X		

HMR T-2135(Orig. 12/66)

02-Sha-05

SUMMARY OF RELATIVE COMPACTION DATA

95%

TABLE 4 (contd)

Cont. 026724

Date	Test No.	Relative Compaction, %							Accept	Reject	Remarks
		#1	#2	#3	#4	#5	#6	Avg.			
9-22-66	AB-13	85	79	85				83		X	
"	AB-14	94	86	92				91		X	
"	AB-15	96	95	96				96	X		
"	AB-16	94	96	96				95	X		
"	AB-17	96	94	97				96	X		

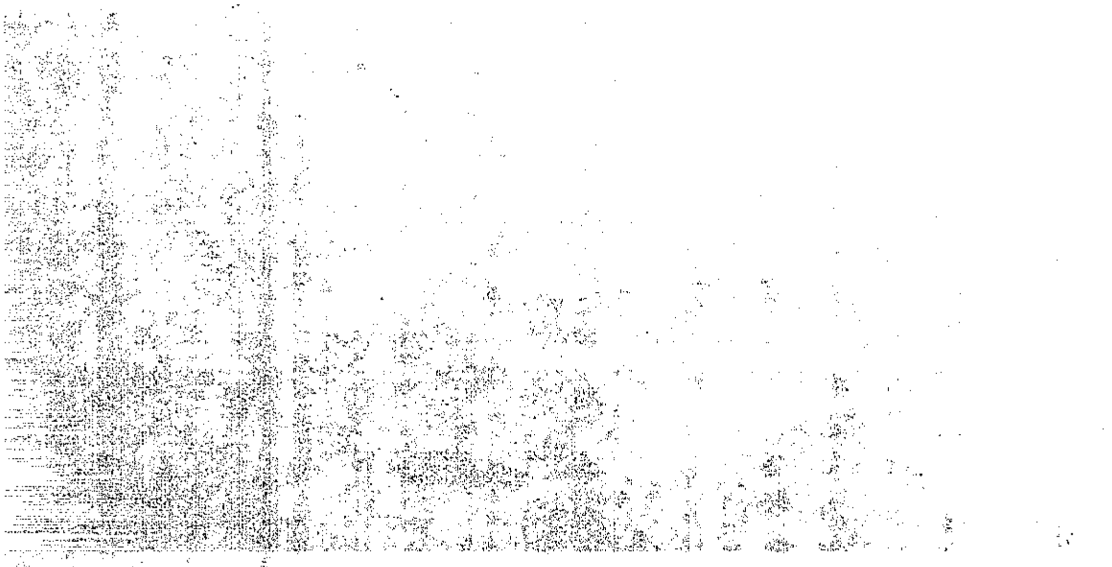
HMR T-2135(Orig. 12/66)

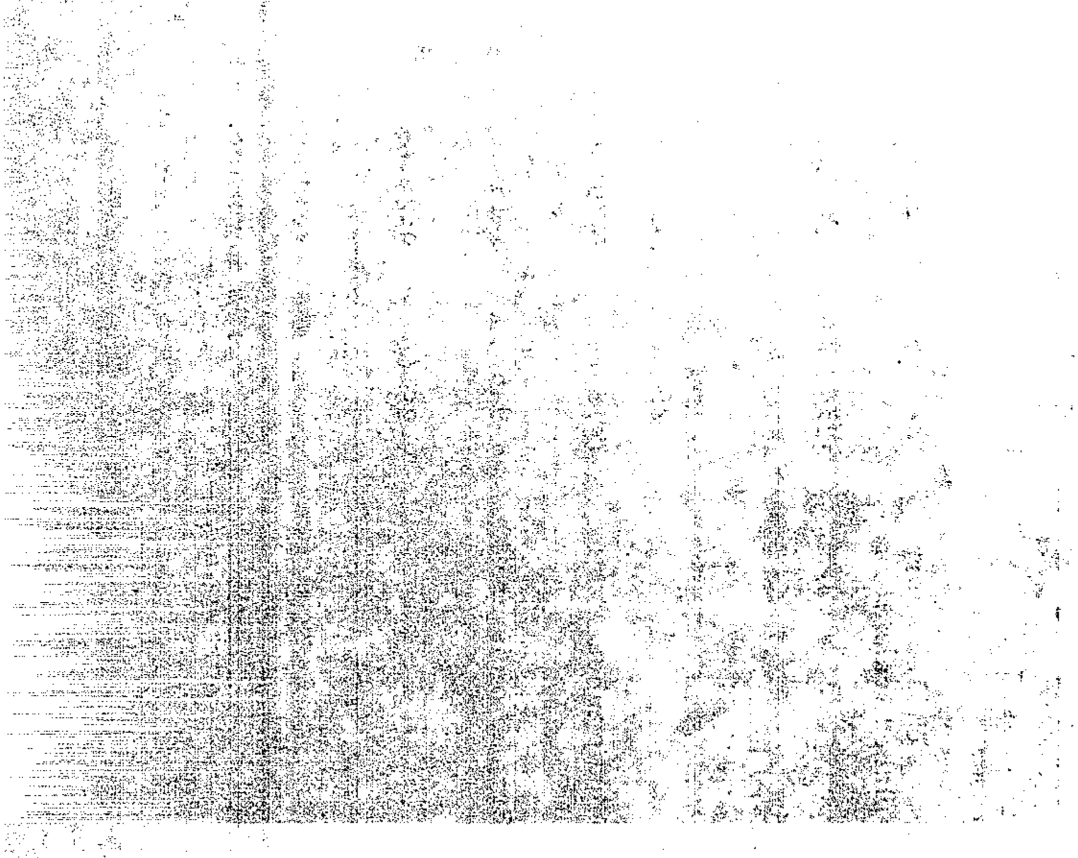
TABLE 5

Record of Nuclear Gage Malfunctions

Description of Malfunction	Date Gage Out	Date Back on Job	Downtime Working Days
Mud & water in base of gage caused high voltage to become erratic	11-18-65	11-22-65	2
Moisture from lst malfunction caused short, density would not count-replaced transitors	12-7-65	12-23-65	16
Broken wire in cable	2-23-66	2-24-66	1
Broken wire in cable, battery loose - transmission rod bent.	3-31-66	4-8-66	4
Cable interconnector broken	4-25-66	4-26-66	1
Density counts dropped, pickup tubes corroded from lst malfunction	7-13-66	7-20-66	8
High temperature caused erratic moisture counts	8-9-66	8-15-66	5
Broken wire in cable	9-29-66	9-29-66	1
		Total	38 days

$$\frac{\text{downtime}}{\text{working days}} \quad \frac{38}{275} = 14\% \text{ downtime}$$





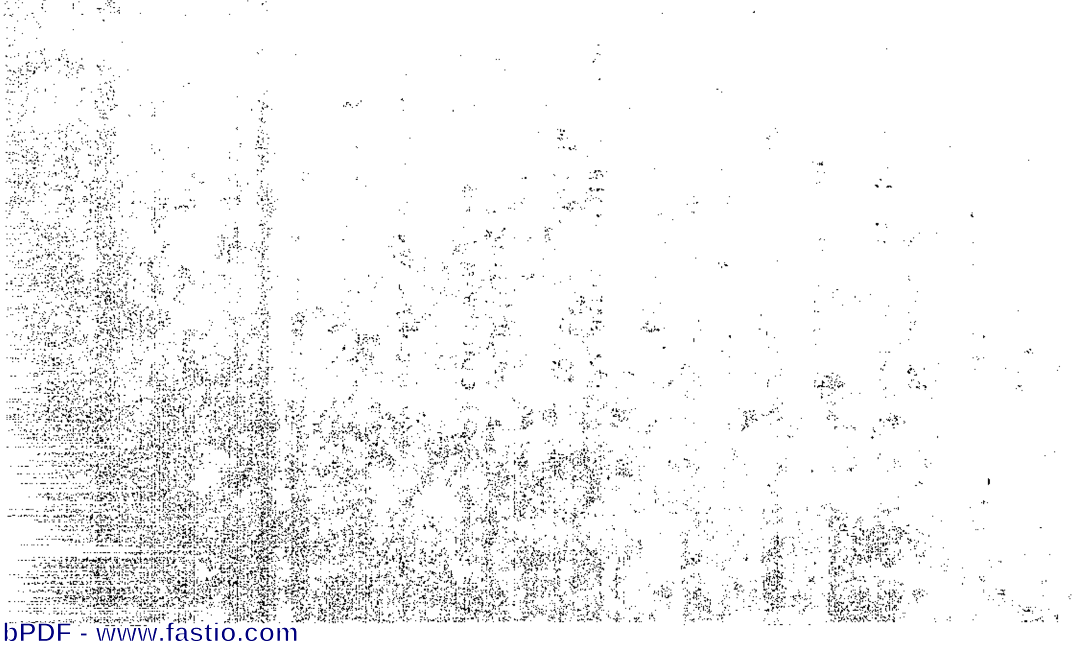
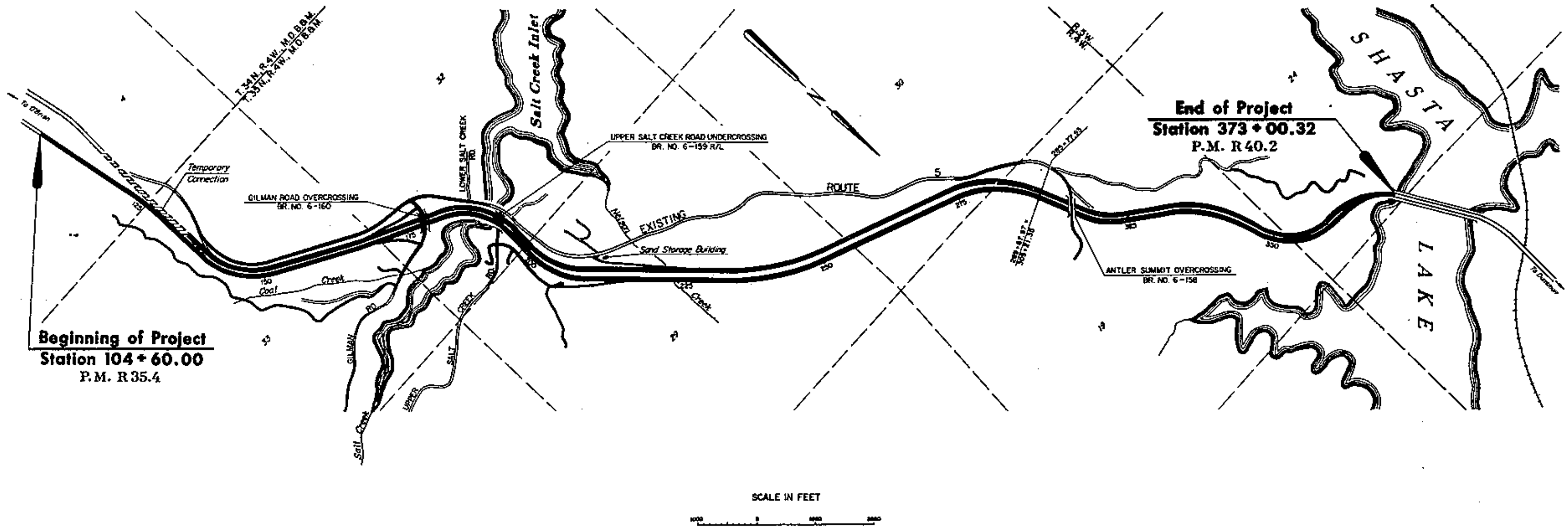


Figure I

In Shasta County between 1.9 miles north of O'Brien and the Sacramento River Bridge

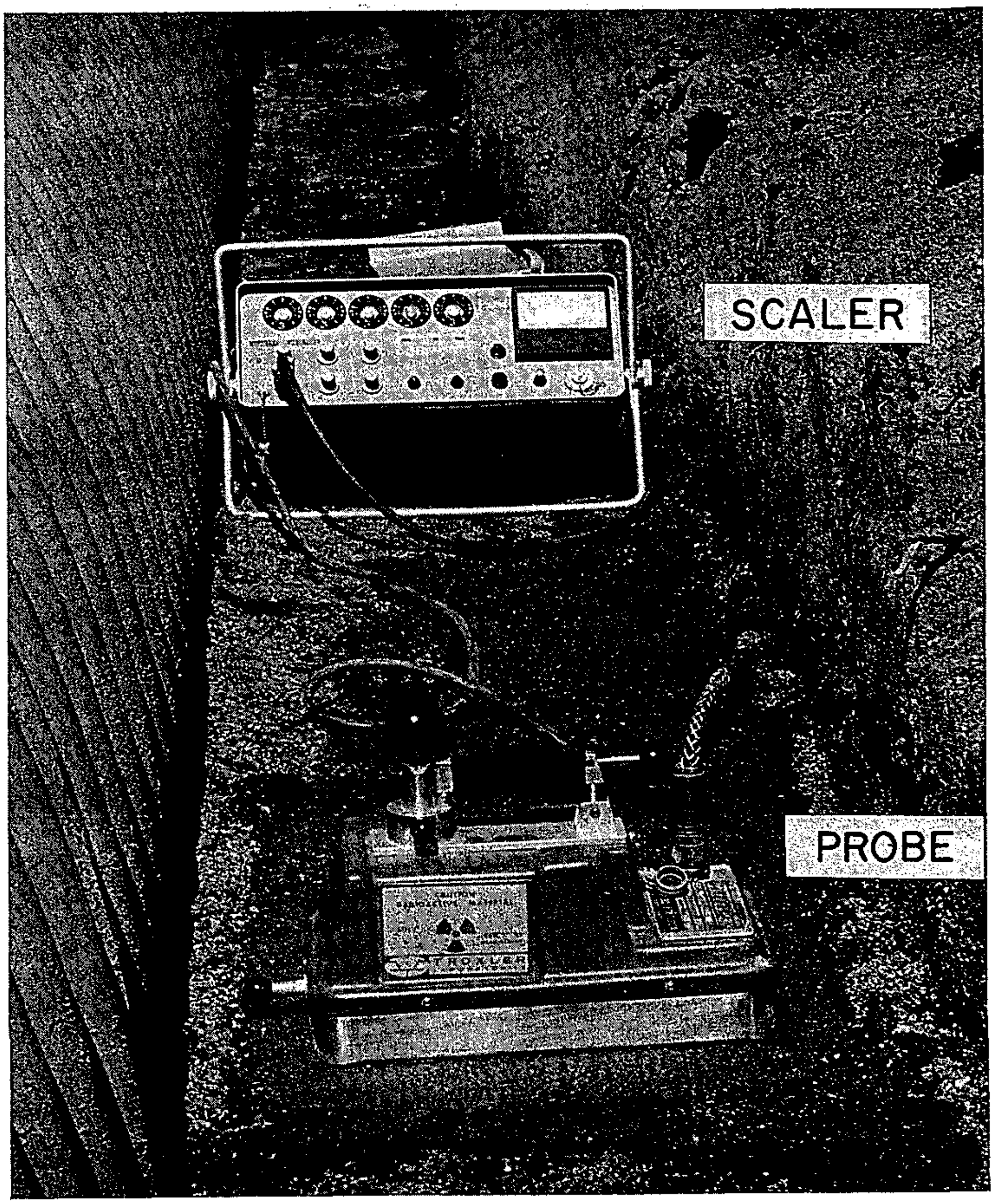
FREEWAY

by resolution of the California Highway Commission on August 23, 1961



Length of Project : 4.7 Miles

Figure 2



TROXLER NUCLEAR MOISTURE DENSITY GAGE

DENSITY CALIBRATION OF TROXLER S.N. 208

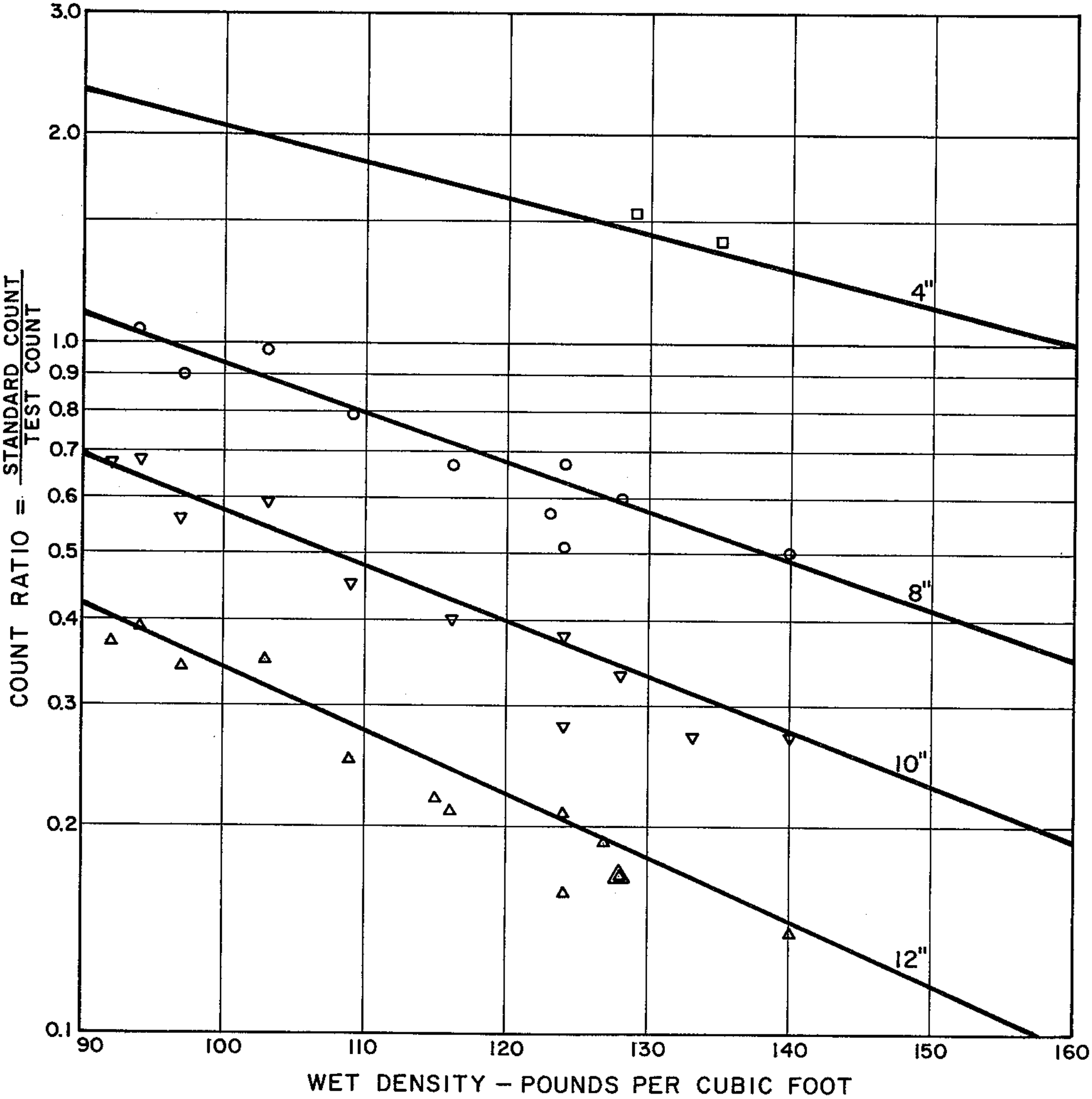
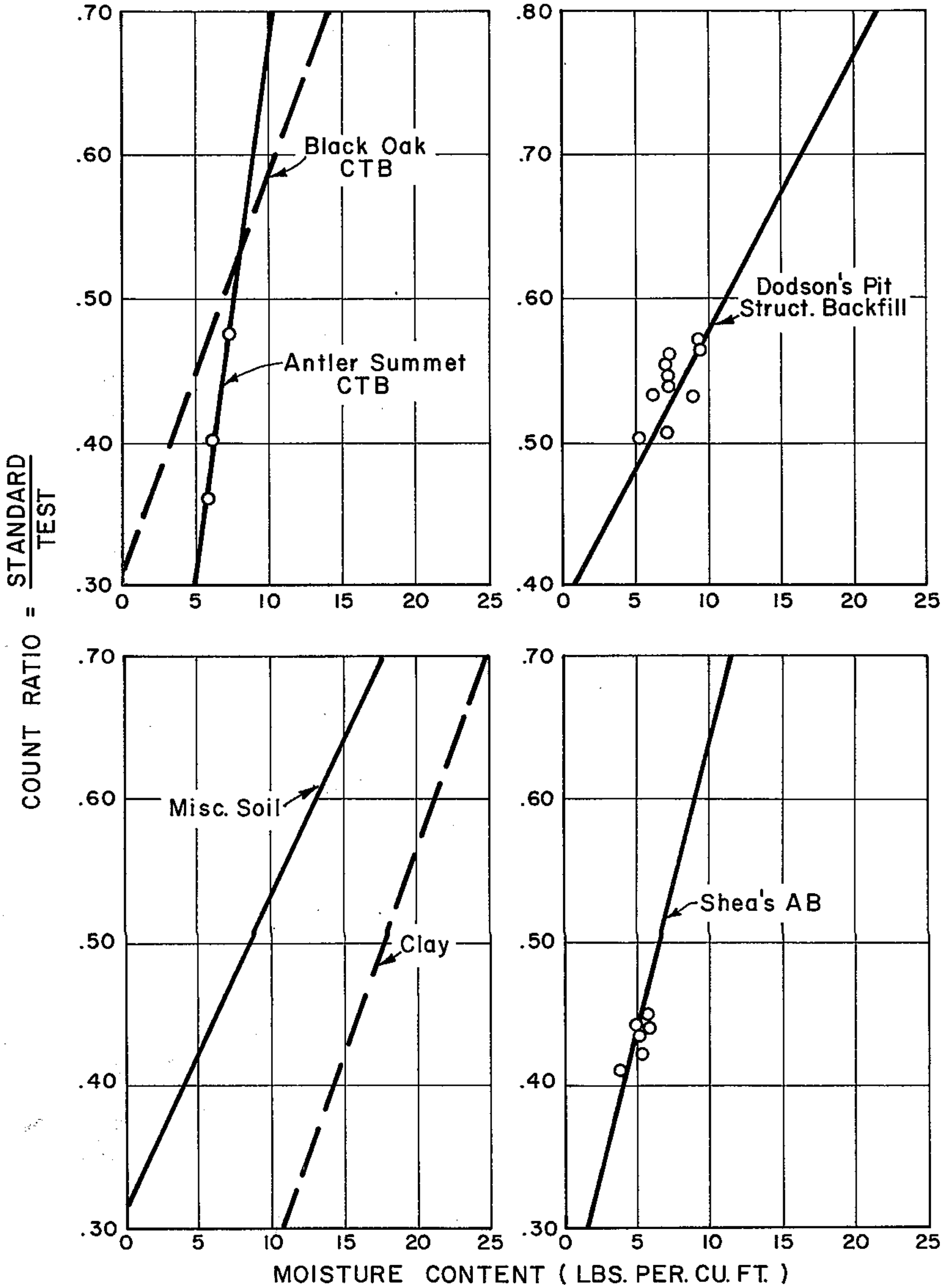


Figure 4

MOISTURE CALIBRATION CURVES



SUMMARY OF MOISTURE CALIBRATION CURVES

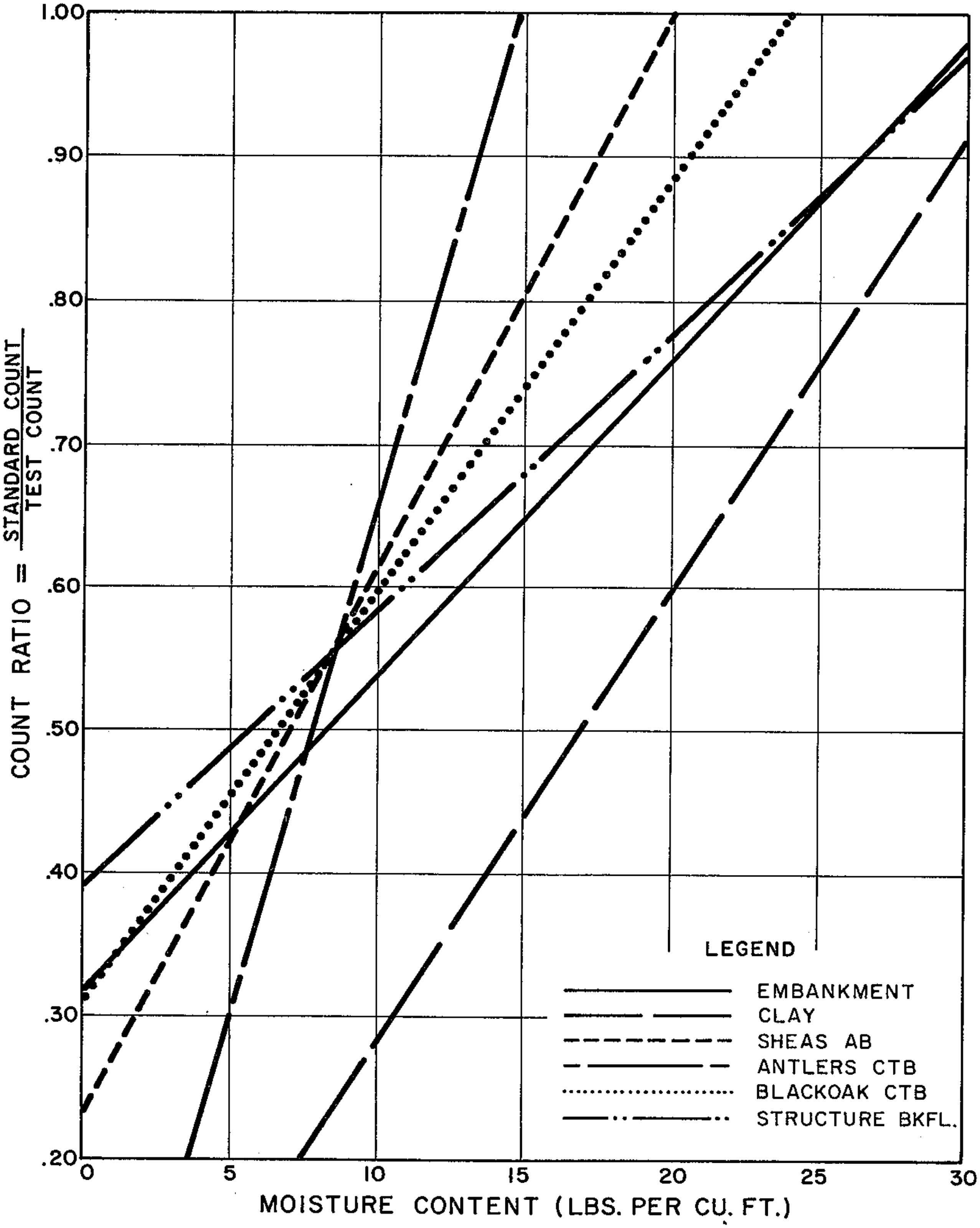
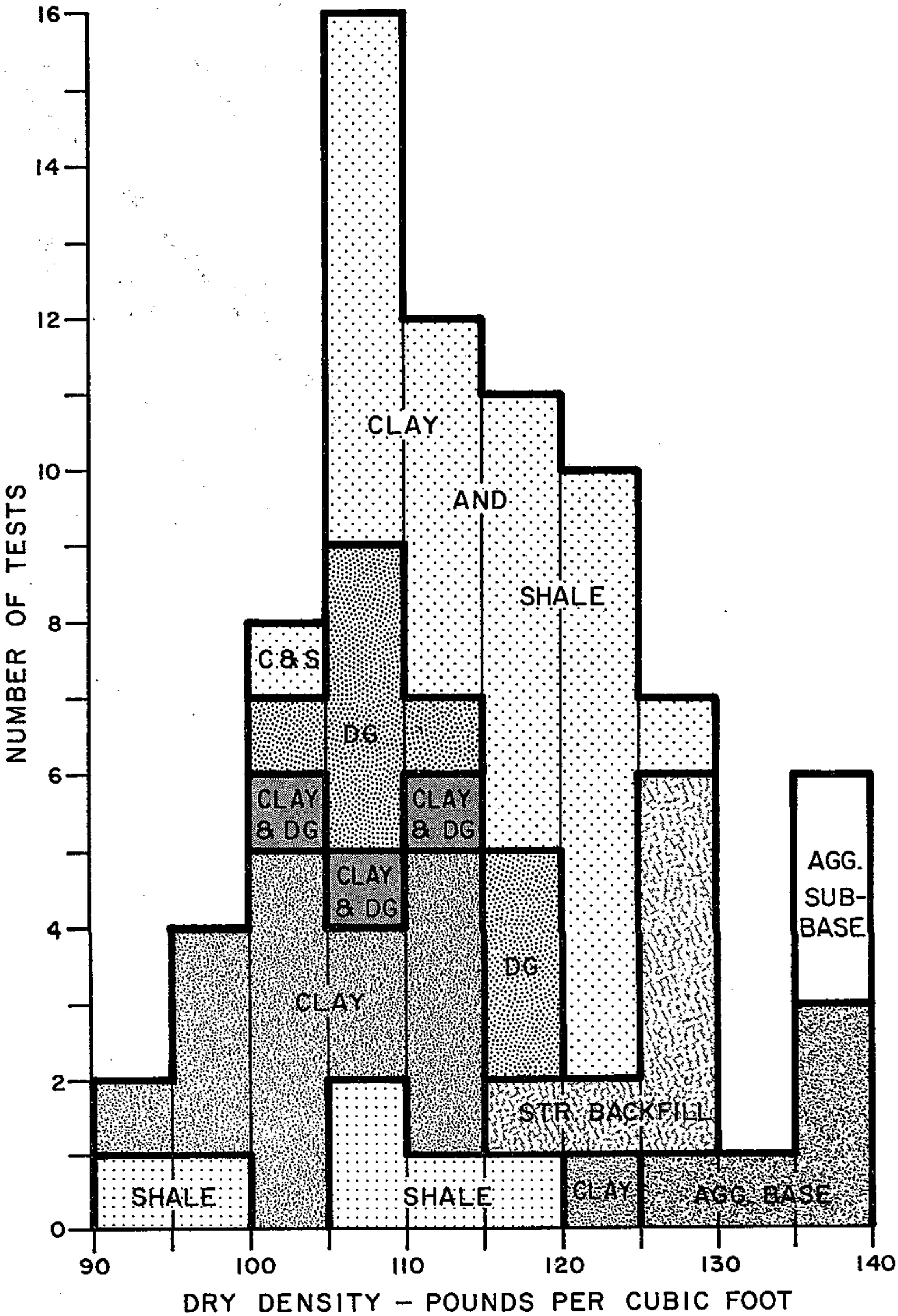


Figure 6

FREQUENCY DISTRIBUTION OF TEST MAXIMUM DENSITIES WITHOUT OVERSIZE ROCK CORRECTION



FREQUENCY DISTRIBUTION OF TEST MAXIMUM DENSITIES WITH OVERSIZE ROCK CORRECTION

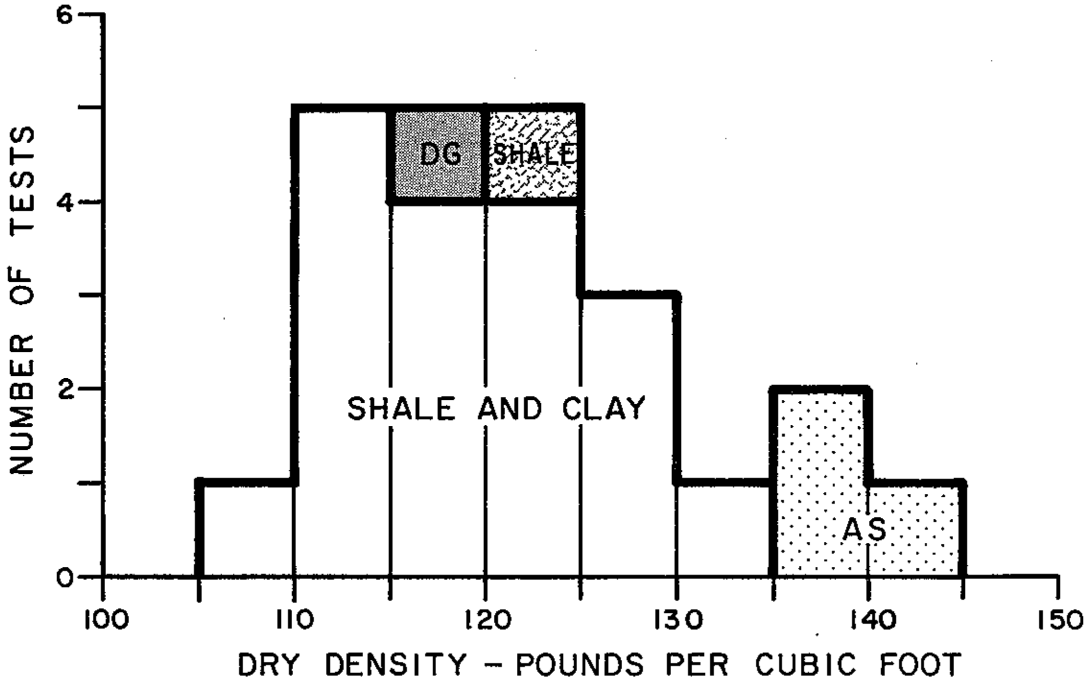
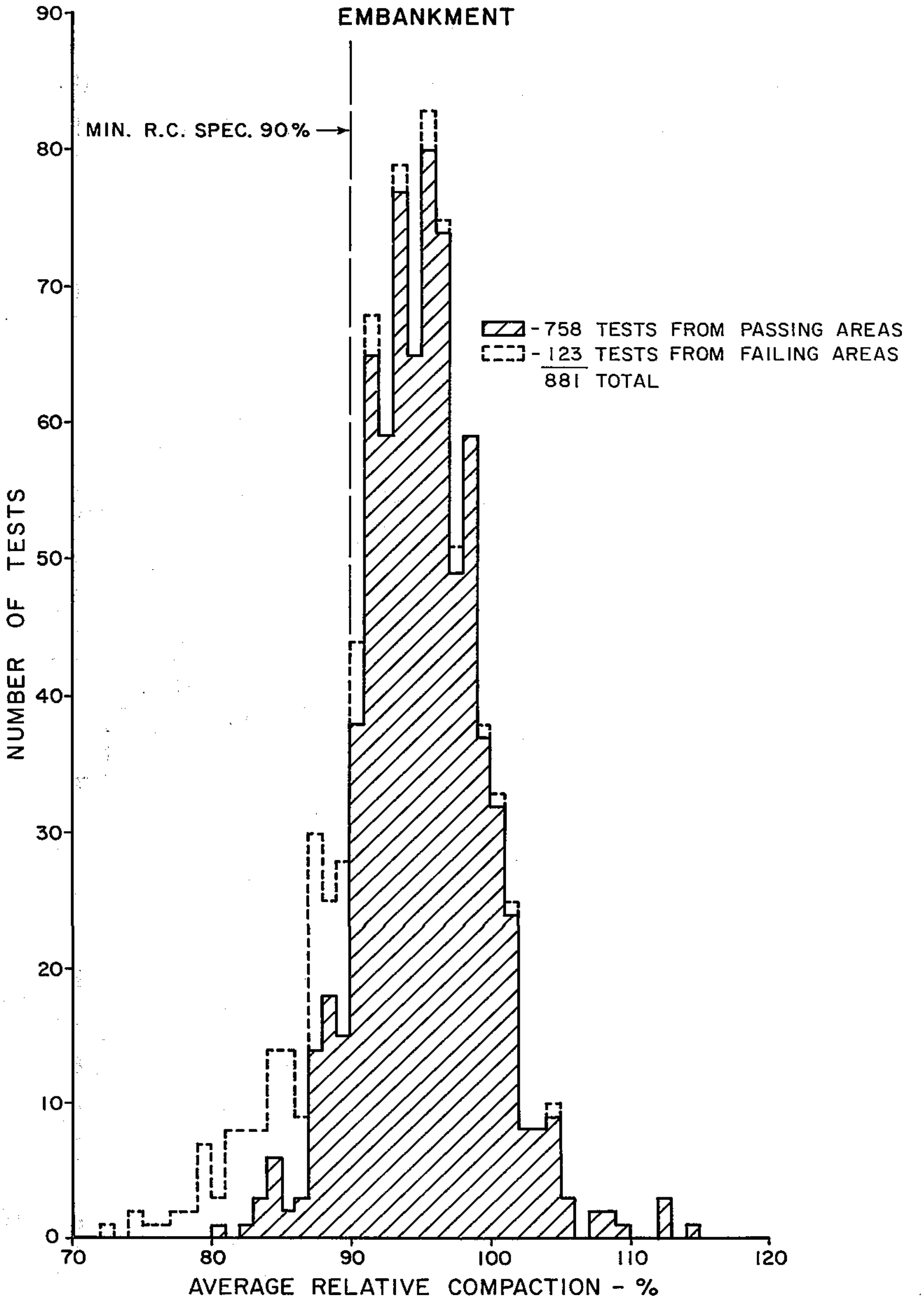


Figure 8

FREQUENCY DISTRIBUTION OF RELATIVE COMPACTIONS AT INDIVIDUAL TEST SITES



FREQUENCY DISTRIBUTION OF RELATIVE COMPACTIONS AT INDIVIDUAL TEST SITES

STRUCTURE BACKFILL AS, AB, CTB, OG.

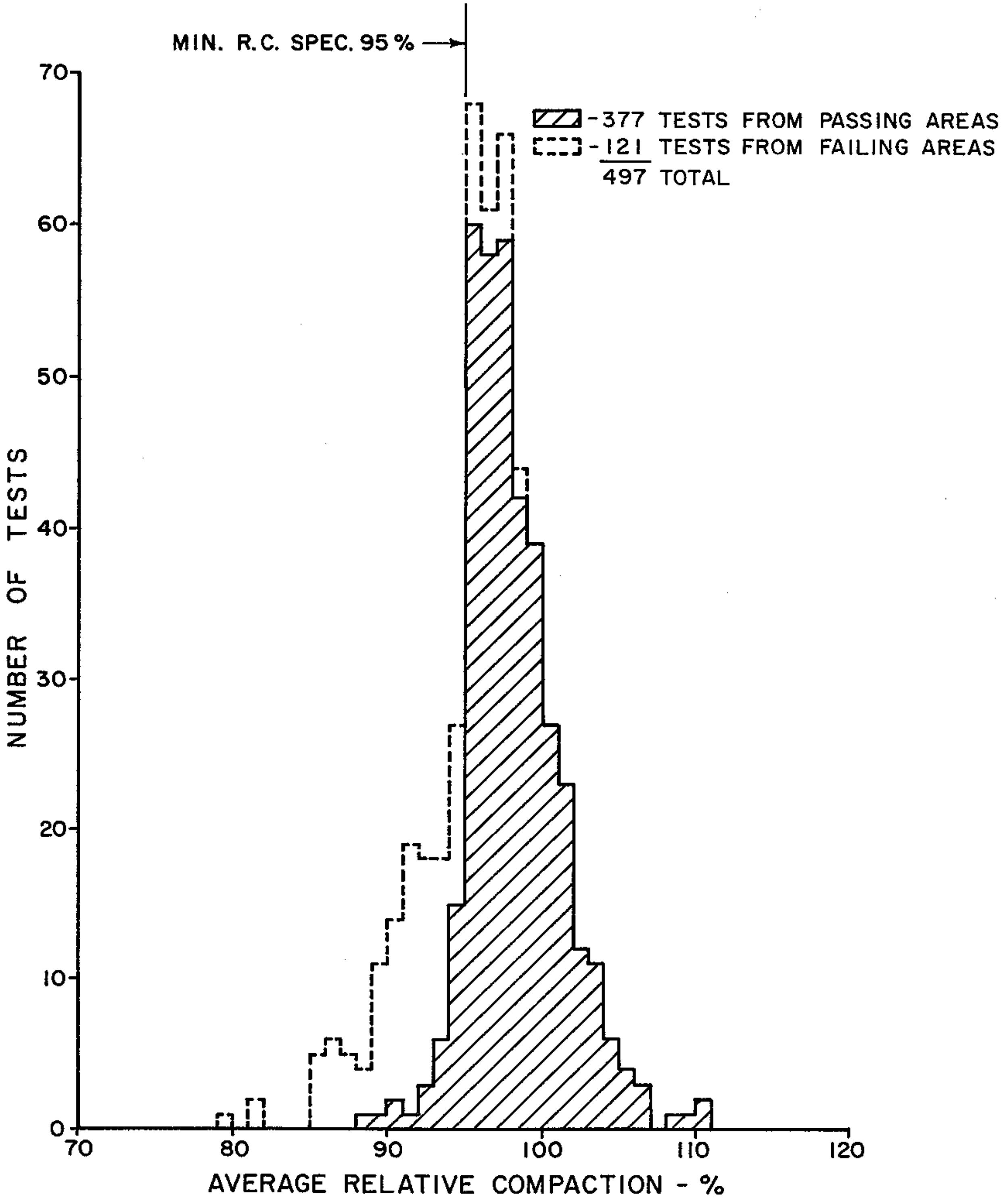
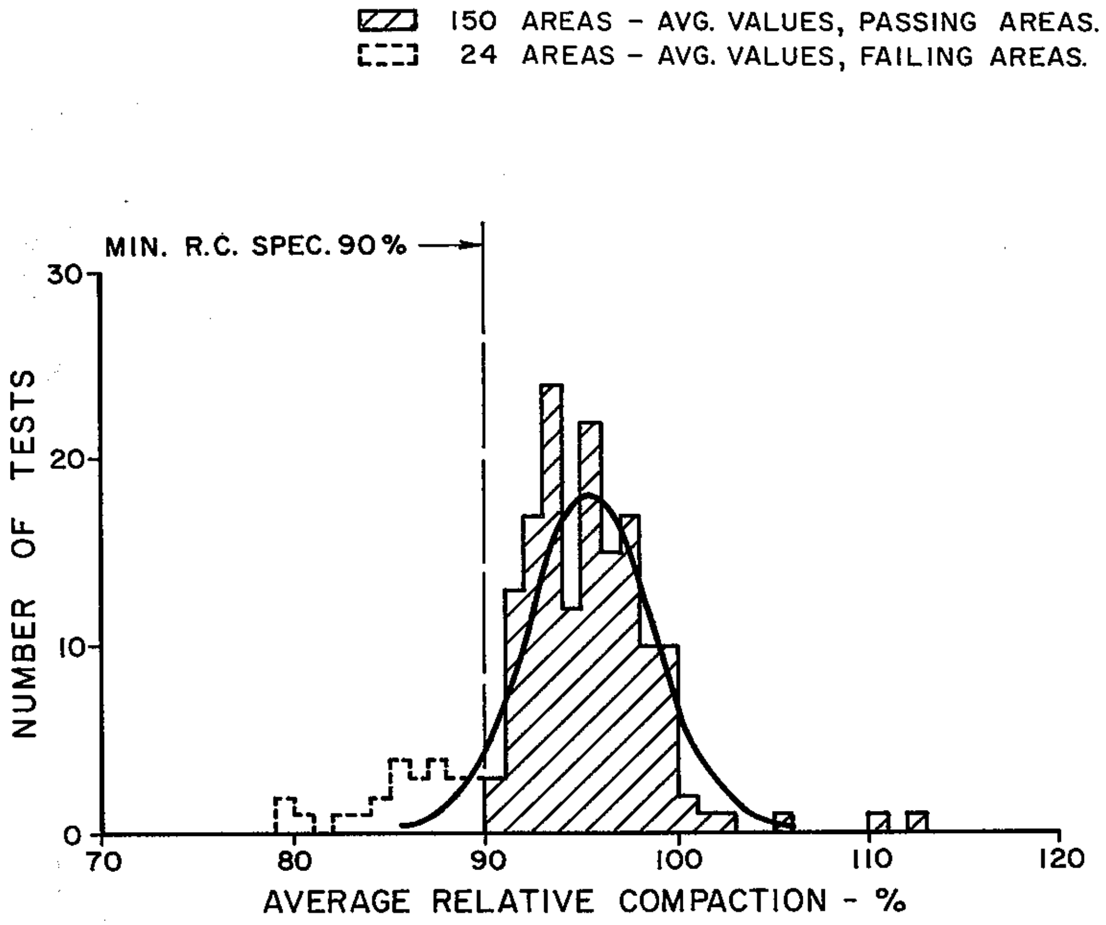


Figure 10

FREQUENCY DISTRIBUTION OF AVERAGE RELATIVE COMPACTIONS FOR AREAS

EMBANKMENT



FREQUENCY DISTRIBUTION OF AVERAGE RELATIVE COMPACTIONS FOR AREAS

STRUCTURE BACKFILL AS, AB, CTB, OG.

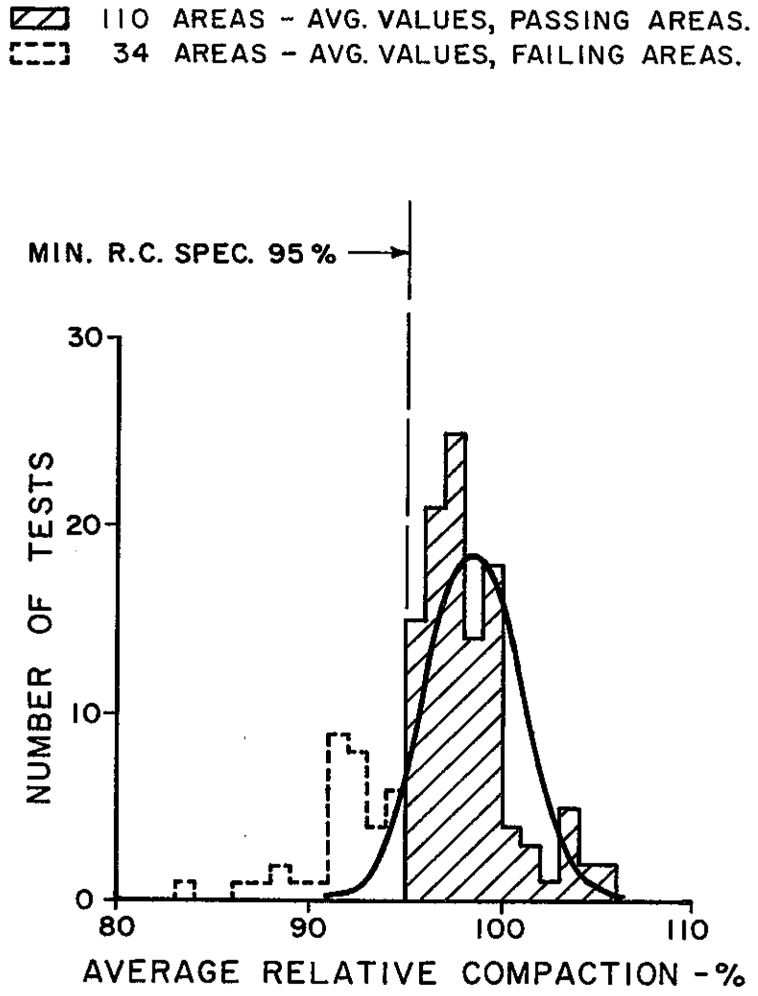


Figure 12

FAILING AREAS IN WHICH 90% R.C. WAS REQUIRED

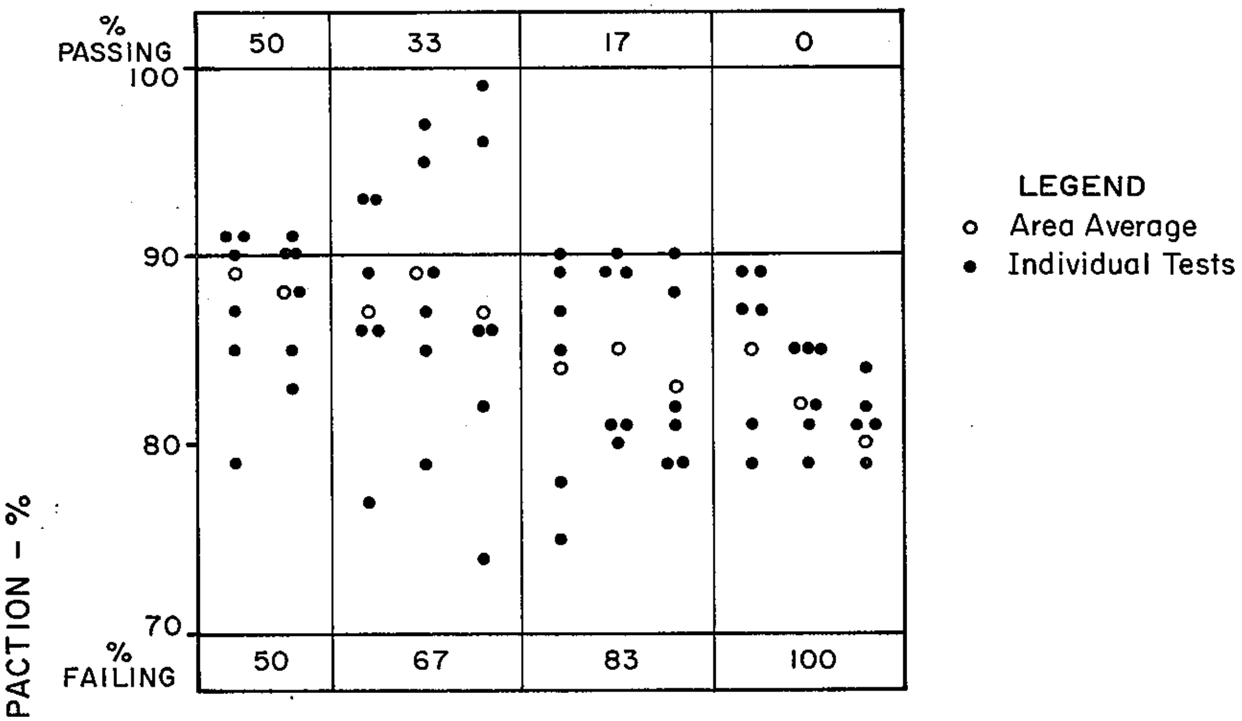
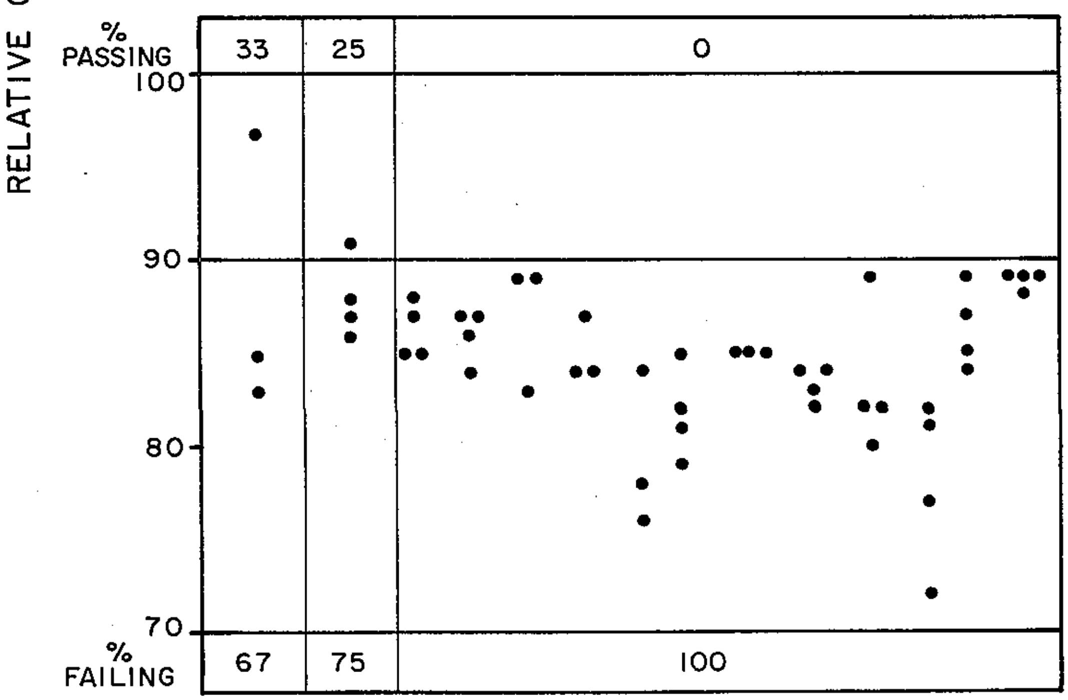


Figure 13

AREAS WHERE TESTING WAS TERMINATED*



*TERMINATION OF TESTING WAS DUE TO OBVIOUSNESS OF SUBSTANDARD AREA. (SEE TEXT)

Figure 14

STRUCTURE BACKFILL, AB, AS, & CTB

FAILING AREAS IN WHICH 95 % R.C. WAS REQUIRED

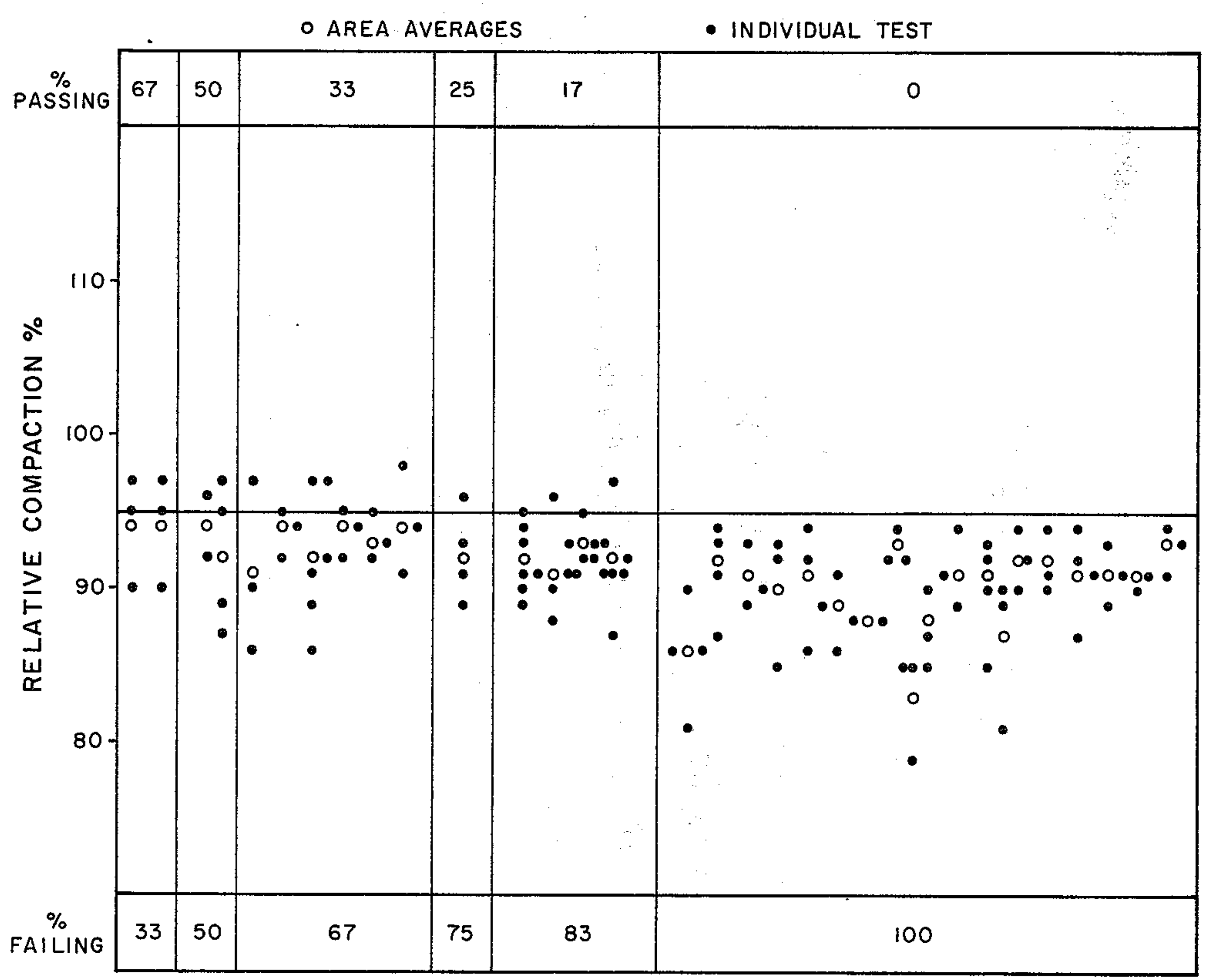


Figure 15

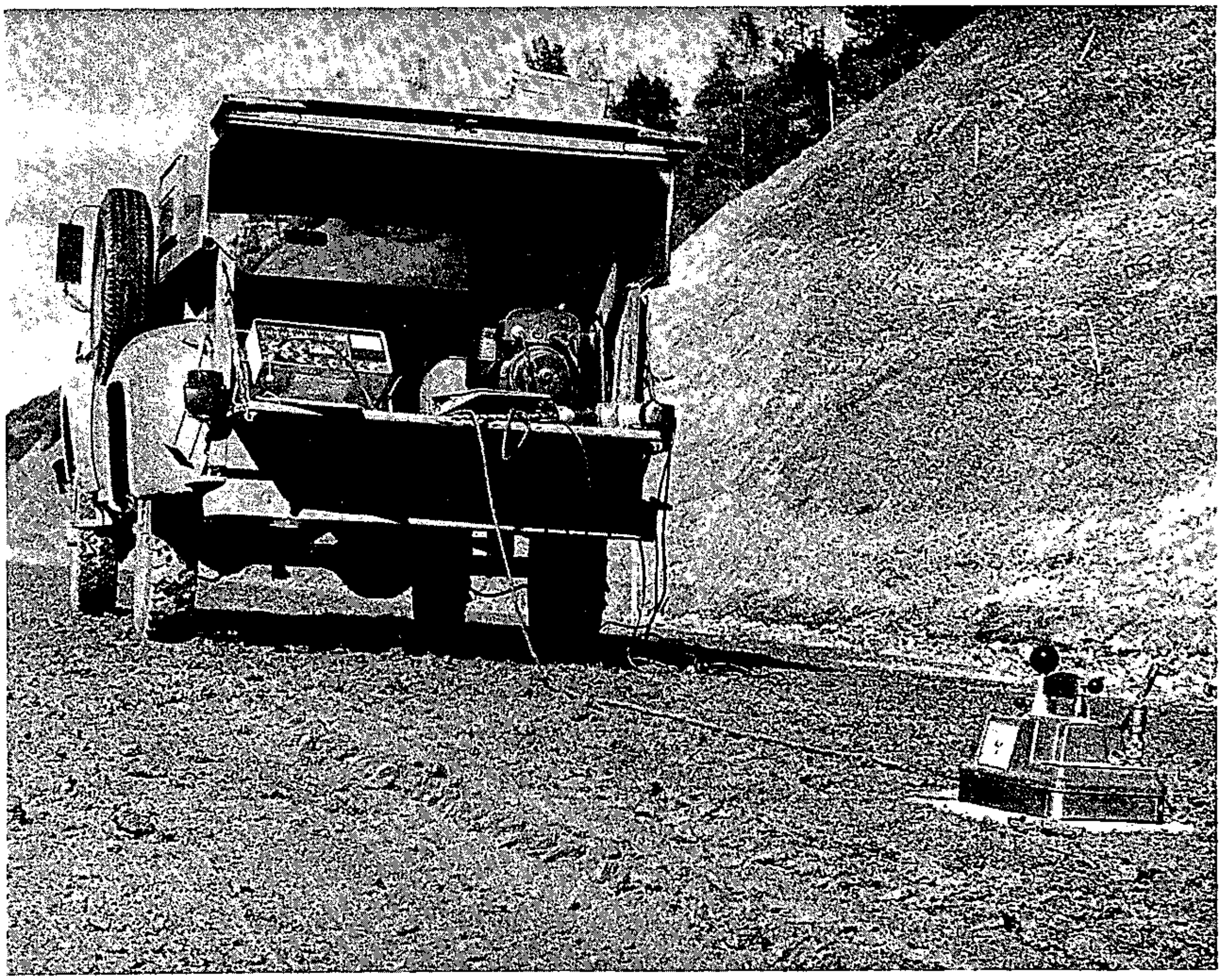


Illustration of vehicle used for transportation of nuclear test equipment.

COPY

July 18, 1966
Redding, California

Materials and Research Department
Division of Highways
Sacramento 19, California

Attention W. G. Weber

Dear Sir:

Submitted for your consideration is:

REPORT

ON

FIELD USE OF TROXLER NUCLEAR MOISTURE AND DENSITY GAGE FOR COMPACTION CONTROL ON CONTRACT 02-026724

02-SHA-5-R35.4/R40.2

FAP I-005-8 (40) 697

IN DISTRICT 02 BETWEEN 1.9 MILES NORTH OF O'BRIEN AND THE SACRAMENTO RIVER BRIDGE

RESIDENT ENGINEER	J. V. KELLY
LABORATORY WORK BY	F. SHEPERSON
	J. SULLIVAN

A. Summary

For the past thirteen months, a Troxler moisture and density gage has been used on this project to measure in-place densities of newly constructed embankments, structure backfill, Class 5 aggregate subbase, Class 2 aggregate base, and Class B road mixed cement treated base.

Use of the gage, with the exception of minor revisions, was in conformance with Test Method No. T-231-B.

In general the instrument has been relatively trouble and maintenance free. Occasional malfunctions have been due to moisture condensations within the gage and problems with the cord connection to the gage. These were easily remedied by drying out the gage and replacing the cord. As of this writing our first serious breakdown has occurred. One or both electrical connections to the geiger tubes were corroded; use of the gage will be lost one week. A replacement was obtained from headquarters materials and research and no loss in testing efficiency resulted.

Outside of a delay in obtaining a properly equipped transporting vehicle, there has been no difficulty in adhering to applicable laws regarding health safety , transportation, storage, and signing regulations.

The following outline pinpoints specific problems with the use of the gage and test method T-231-B.

B. Test Method Critique

The test method and area concept have caused no difficulties in control. Towards the middle of the contract we decided to refrain from rejecting a portion of an area tested. The six tests were merely averaged and compared to the average values of the test maximum densities representative of the in-place material. The entire area was either accepted or rejected.

Considerable operator judgement is inherent in any visual means of classifying material. We have relied heavily on this in selecting the appropriate test maximum density. Ogive distribution curves were not used due to the variety of materials and mixtures of materials encountered.

A minimum of three test sites should be acceptable if the area being tested is small.

Allowable count variations should depend on the material being tested, e.g., close for sand and clay, higher tolerance in rock.

C. Troxler Gage Critique

We found the manufacturers density curves to be accurate for all materials encountered.

The moisture vs. count ratio curve had to be developed for each material used on the contract. Wide variations in these calibration curves were noted. Early in the contract we experienced malfunctions of the gage when used to measure moisture in saturated soils or when used in the rain. This type of usage was discontinued.

Minor operational difficulties resulted from the very stiff cord supplied by the Troxler Company; the necessity of the hole being at right angles to the surface being tested, and site preparation in rocky material.

D. Soil Types and Compaction Methods

Soil Type	Compaction Method
1. Embankment	
Shale	Routing rubber tired scrapers
	Heavy watering
	Sheepsfoot rollers
Clay	280 & 380 Michigan rubber tired dozers
	Routing rubber tired scrapers
	Close attention to watering
2. Bases	
Class 5 Aggregate Subbase	Grid roller to break down, finish with steel wheel roller
Class 2 Aggregate Base	Steel and rubber tired rollers
Cement treated base	Steel and rubber tired rollers
3. Structure Backfill	Hand guided impact types
	Heavy watering

E. Cost of Sand Volume Testing Compared to Nuclear

It is felt that the same amount of time is expended on both test methods.

Approximately 850 man hours have been expended by two lab technicians on compaction control. About 150 hours of this was spent determining test optimum densities.

F. Effect on Contractors Costs

The district and myself feel this is indeterminate. The contractor's operations are facilitated by quicker test results, but the increase control afforded by the nuclear coverage will sometimes increase costs.

MATERIALS AND RESEARCH DEPART

State of California
Department of Public Works
Division of Highways

Test Method No. Calif. T-231-B
December 30, 1964
(4 pages)

METHOD OF TEST FOR RELATIVE COMPACTION OF SOILS BY NUCLEAR METHODS

SCOPE

The nuclear method of test shall be used to determine the in-place moisture and density of compacted soils and aggregates. The in-place density is the density of a soil as it exists in either the natural ground, in constructed earthwork, or after being processed and compacted. The test maximum density shall be determined as specified in Test Method No. Calif. 312 for Classes A and B Cement Treated Base and in Test Method No. Calif. 216 for untreated materials, Classes C and D Cement Treated Base and lime treated soils and aggregates.

A. APPARATUS

1. A nuclear gage for determining soil moisture and density.
2. A portable scaler to count the radiation received by the detector in the nuclear gage.
3. A standardizing device to check the operation of the gage and scaler.

B. STANDARDIZATION OF EQUIPMENT

1. At least twice a day standardize the gage to check the operation of the equipment.
2. Place the gage upon the standardizing device and take counts after the scaler has been turned on for at least fifteen minutes with the gage connected. Make five or more one-minute counts.
3. Discard any counts deviating from the average by over 200 counts and average the remaining counts. This average is to be within 250 counts of the average supplied with the equipment.

C. CALIBRATION

1. Calibration curves relating the counts obtained with the nuclear gage to the soil moisture and density will be supplied with the gage at the start of the contract.
2. Obtain comparative sand volume tests at selected intervals at the same locations as the nuclear tests. Perform the sand volume test as described in Test Method No. Calif. 216. This must be done for each general soil type encountered on the project.
3. After obtaining several comparisons the calibration relating nuclear counts to density may be modified by the method of least squares assuming a linear relationship.

D. DETERMINATION OF NUCLEAR COUNTS.

1. Preparatory to making a nuclear determination, clear away all loose surface material and obtain a plane surface at least 2 feet square. In areas compacted by pneumatic-tired or smooth-wheel rollers, remove disturbed surface material to a depth of not less than 2 inches below the final surface on which the rollers have operated. Where sheepsfoot and similar type tamping rollers have been used, remove the loose surface material to a depth of not less than 2 inches below the deepest disturbance by the roller. The nuclear test may be conducted when the surface is plane to within 1/8 inch under the area covered by the gage.

2. Where a transmission type density gage is to be used, make a small hole 12 to 15 inches deep with the equipment supplied. This hole must be at 90 degrees with the plane surface. No hole is required for backscatter type gage.

3. Fill in the minor depressions, not exceeding 1/8 inch, with native fines. Place the nuclear gage on the soil surface so that all points of the bottom of the gage are in contact with the soil. Place the transmission type gage so that the rod on the gage is over the hole, and then push the rod into the hole to the desired depth.

4. Obtain a reading over a one-minute interval. Then rotate the gage 90 degrees over the same center point and obtain another one-minute reading. If these two readings do not check within 250 counts, obtain two additional readings by rotating the gage over the same center point. Average the two or more readings which are within 250 counts. This average reading constitutes one nuclear test.

E. DETERMINATION OF MOISTURE AND DENSITY OF THE SOIL

1. Using the calibration curves, convert the averaged readings to wet density and moisture content. Show the wet density in pounds of material per cubic foot and show the moisture content in pounds of water per cubic foot.

2. Determine the dry unit weight by subtracting the moisture from the wet density.

F. NUMBER AND LOCATION OF NUCLEAR TESTS

1. The nuclear test will utilize the area concept. That is, a series of tests will determine whether to accept or reject an entire area. Perform six or more nuclear tests in each area. The engineer shall determine the area based on uniformity of factors affecting nuclear testing.

2. Divide the area into two or more sections of approximately equal size. Perform two or more nuclear tests upon each section with the locations of the nuclear tests being of a random nature. (For special cases one section may be tested with three nuclear tests and considered an area.) Determine the moisture and density of the soil by the nuclear tests as described in part D and E above.

F. NUMBER AND LOCATION OF NUCLEAR TESTS (Continued)

3. Average these six or more tests and perform the maximum density test on the soil obtained from the location of the nuclear test which has a value just below the average value. Determine the maximum density as specified in Test Method No. Calif. 312 for classes A and B CTB and Test Method No. Calif. 216 for all other treated and untreated soils and aggregates.

4. Care must be taken that the same soil type exists over the given area. This is so that the one maximum density test is consistent with the nuclear tests.

5. Using the maximum density test, calculate the per cent relative compaction for each nuclear test. The average of all of the nuclear determined relative compaction tests must be above the required compaction value. No more than one third of the individual tests may be below the required compaction value. If the average of all tests in one section fail to meet the required compaction value, this section may be failed even though the other sections may be passed. Thus, either sections or areas may be passed or failed.

6. When sufficient maximum density tests have been obtained, a value may be established for a soil type and only occasional check maximum densities made on that soil type.

G. DETERMINATION OF RELATIVE COMPACTION

Determine the relative compaction by either of the following:

1. Per Cent Relative Compaction

$$= \frac{\text{In-Place dry density}}{\text{Test maximum dry density}} \times 100$$

Where

In-place dry density is determined by the use of the nuclear gages as herein described.

Test maximum dry density is determined as described in Test Method No. Calif. 312 for Classes A and B CTB and Test Method No. Calif. 216 for all other treated and untreated soils and aggregates.

G. DETERMINATION OF RELATIVE COMPACTION (Continued)

2. Per Cent Relative Compaction = $\frac{L_{(nuclear)}}{g_m} \times 100$

Where

$L_{(nuclear)}$ = in-place wet density as determined by the use of the nuclear gages herein described.

g_m = maximum adjusted wet density of the compacted test specimens as described in Test Method No. Calif. 216.

REFERENCES

Test Method No. Calif. 216
Test Method No. Calif. 312
End of Text on Calif. T-231-B